Quantum Phase Transitions and non-Fermi-liquid Physics

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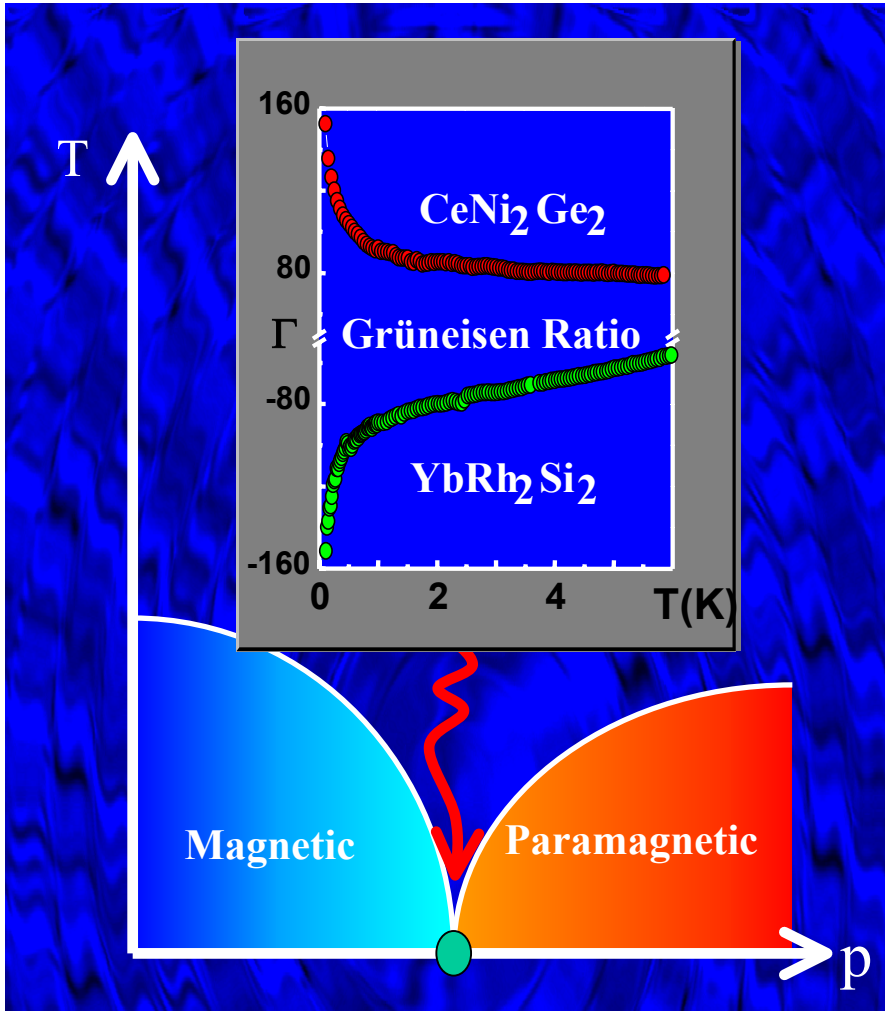
•Quantum criticality is of extensive current interest: it leads to the breakdown of Fermi liquid theory --the standard theory of metals -- and to the emergence of new quantum states such as superconductors.

•Here, we predict a mathematical irregularity called divergence in the Grüneisen ratio – the relative value of thermal expansion to heat capacity – at any quantum critical point (QCP, figure at right). This establishes a thermodynamic means to classify QCPs.

•In an experiment-theory collaboration, we report the observation of such a divergence in two (rare-earth-based) heavy fermion metals; see figure inset. The result in YbRh2Si2 provides evidence for local quantum criticality as proposed earlier in Q. Si *et al.*, Nature 413, 804 (2001).

Divergence of Grüneisen Ratio at Magnetic QCPs



Quantum Phase Transitions and non-Fermi-liquid Physics (cont.)

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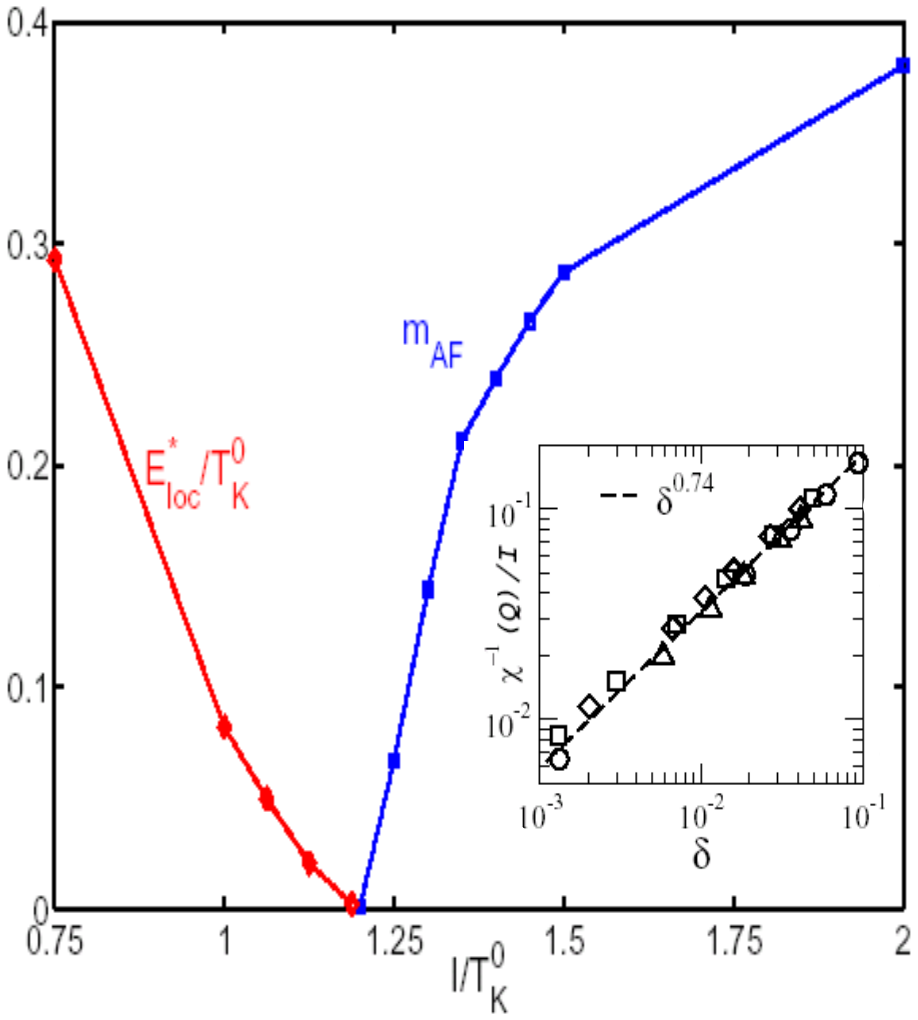
- Quantum critical point is a stage matters pass through as they change phases at absolute zero. An outstanding question is whether or not quantum fluctuations - the effects of Heisenberg's uncertainty principle - are simply fluctuations of an ``order parameter'', as classical thermal fluctuations are known to be.

- We have previously proposed that, in heavy fermion metals, quantum fluctuations reflect a destruction of Kondo effect. Such a QCP is called locally quantum critical.

- Here, we report two kinds of evidence for the theory using a quantum Monte-Carlo method: a) vanishing of the effective Kondo scale, E_{loc}^*, at the onset point of the magnetic order parameter, m_{AF} (main plots); b) fractional scaling exponent in the spin dynamics at the QCP (figure inset).

Destruction of the Kondo Effect at a Magnetic QCP



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Publications on Grüneisen Ratio

•L. Zhu, M. Garst, A. Rosch, and Q. Si, Phys. Rev. Lett. 91, 066404 (2003).

• R. Küchler *et al.*, Phys. Rev. Lett. 91, 066405 (2003) [a collaboration with F. Steglich's experimental group, Max-Planck Institute, Dresden Germany].

Publications on Local Quantum Critical Point

•D. Grempel and Q. Si, Phys. Rev. Lett. 91, 026401 (2003).

•J.-X. Zhu, D. Grempel, and Q. Si, Phys. Rev. Lett. 91, 156404 (2003).

Education and Outreach

• The PI's group has been training two graduate students (J. Sun and L. Zhu), two postdocs (S. Kirchner and E. Pivovarov) and one undergraduate student (O. Rambow), and previously involved two other undergraduates for their thesis research .

• The PI wrote a pedagogical article on quantum phase transitions at the beginning graduate student level [APCTP Bulletin vol. 11-12, pp. 7-12 (2003)], and organized a workshop on Non-Fermi Liquid Behavior and Quantum Phase Transitions, at the Lorentz Center, Netherlands in 2003 (co-organizers G. Stewart and A. de Visser).

•The PI participated in the Contact Congress initiative, March 2004.